FISSION SYSTEMS FOR MARS EXPLORATION. M. G. Houts,[1] T. Kim,[1] D. J. Dorney,[1] M. S. Swint[1]
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Introduction: Fission systems are used extensively on earth, and 34 such systems have flown in space. The energy density of fission is over 10 million times that of chemical reactions, giving fission the potential to eliminate energy density constraints for many space missions. Potential safety and operational concerns with fission systems are well understood, and strategies exist for affordably developing such systems. By enabling a power-rich environment and highly efficient propulsion, fission systems could enable affordable, sustainable exploration of Mars.

Potential Fission System Applications: On the surface of Mars, compact fission systems could be used to power in-situ resource ultization (ISRU), to recharge rovers, to provide robust communication capability, and to provide general long term power needs. Power levels could range from the order of 1 kWe (below which radioisotope systems could potentially be used) to greater than 1000 kWe, depending on mission need. Fission systems could be used anywhere on the surface of Mars (including high latitudes) and could be designed to provide full power in all potential Mars environments (including global dust storms). At moderate to high power levels fission systems are signifycantly less massive than alternatives. An artist's conception of a potential 40 kWe fission surface power system (based on an ongoing NASA/DOE project) is shown in Figure 1.

Figure 1. Artists conception of 40 kWe fission surface power system suitable for use anywhere on the moon or Mars.

Abundant thermal power from fission systems may also be useful. In addition to potential ISRU applications, thermal (or electrical) power could potentially be used to heat-sterilize spacecraft to help meet planetary protection requirements.

Fission propulsion systems could be used to efficiently transfer payloads to and from Mars. Nuclear thermal propulsion (NTP) uses fission energy to directly heat a propellant, and could significantly reduce the number of heavy lift launches needed to support a human Mars mission. Nuclear electric propulsion (NEP) uses fission energy to power electric thrusters, and could efficiently transfer large payloads and also support human missions. The use of nuclear thermal and nuclear electric propulsion could significantly reduce the cost of Mars exploration and enable more robust and extensive Mars exploration.

A picture of an NTP engine (tested in 1968) is shown in Figure 2. NTP engines have been ground tested at power levels and temperatures that would would result in a thrust of up to 200,000 lbf and specific impulses exceeding 900 s (roughly twice that of the best chemical engines.

Figure 2. Phoebus-2A Nuclear Thermal Rocket enroute to ground test (1968).

A picture of a Russian in-space fission power system is shown in Figure 3. In-space fission power systems could be used to power satellites and NEP vehicles.

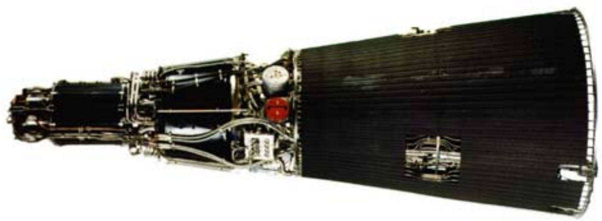

Figure 3. Russian "TOPAZ" space fission power system.

Potential Fission System Concerns: Fission systems must be designed to be affordable. Initial space fission systems could use technologies developed over the past 70 years for terrestrial fission systems, reducing technology development cost. Advances in modeling and computer simulation will also reduce cost. Highly realistic non-nuclear testing will be used when applicable to minimize cost and help ensure that all necessary nuclear testing is properly focused. Although space fission systems are essentially non-radioactive at launch (i.e. prior to extended operation at high power), the pre-launch processing of fission systems may require new or modified facilities. System design and pre-launch processing procedures must be used to ensure the reactor does not inadevertently start when ground personnel are nearby, analogous to designs and procedures used for handling solid rocket motors. High temperature fuels and materials are required for some space fission systems, especially for advanced, very high performance systems. Fission systems have a minimum size below which they are incapable of sustaining a fission chain reaction. The lowest mass fission system flown to date was the 42 kWt (500 We) SNAP-10A with an unshielded mass of 295 kg, and a shielded mass roughly 50% higher. Fission systems are best suited for missions benefitting from nuclear thermal propulsion or from power levels above ~1 kWe (highly mission dependent).

Strategies exist for mitigating concerns associated with space fission systems.

Potential Approach to Developing Fission Systems for Mars Exploration: Although a wide variety of fission systems may eventually be developed, all fission systems have certain fundamental similarities. Launch and operational procedures, design teams, technologies, test facilities, and other capabilities developed for initial fission systems may be applicable to a wide range of systems.

For example, a small (<50 kWe) reactor could be used to provide abundant energy to a robotic outpost on Mars. To help ensure affordability, the system could use fuel developed for terrestrial powerplants or research and training reactors. It may also be possible to use a fuel that would be suitable not only for applications requiring < 50 kWe, but higher power systems or nuclear thermal propulsion systems as well.

Another option would be to develop a small, efficient NTP system to support Mars missions in the 2022 time frame and beyond. The initial NTP system would be designed to prove capability and be readily scalable to a higher thrust NTP system useful for deep-space human missions (including Mars). Experience and capability gained from development of the initial NTP system could be directly applicable to development of surface fission power systems or fission power systems for NEP.

As one example, cermet fuels (uranium fuel contained in a W or Mo metal matrix) could potentially be used for either fission propulsion systems or fission power systems. Modern fabrication techniques enable the use of spherical, coated fuel particles, which should improve cermet fuel performance even beyond the excellent performance demonstrated in the 1960s. The use of modern techniques may also enable development of advanced, highly flexible radioisotope heat sources.

Implications: The benefits from affordable fission systems would permeate the entire space program. Fission systems on Mars could provide power to enable abundant methane, hydrogen, oxygen, and other ISRU products. Systems in permanently shadowed lunar craters could greatly facilitate the mining of lunar ice and the conversion of that ice into propellant. First generation fission propulsion systems are estimated to save up to 3 heavy lift launches per human Mars mission, and advanced propulsion systems could save even more.

Conclusion: Space fission systems could help enable affordable, sustainable exploration of the moon, asteroids, Mars and beyond.

Fission Systems for Mars Exploration

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presented by

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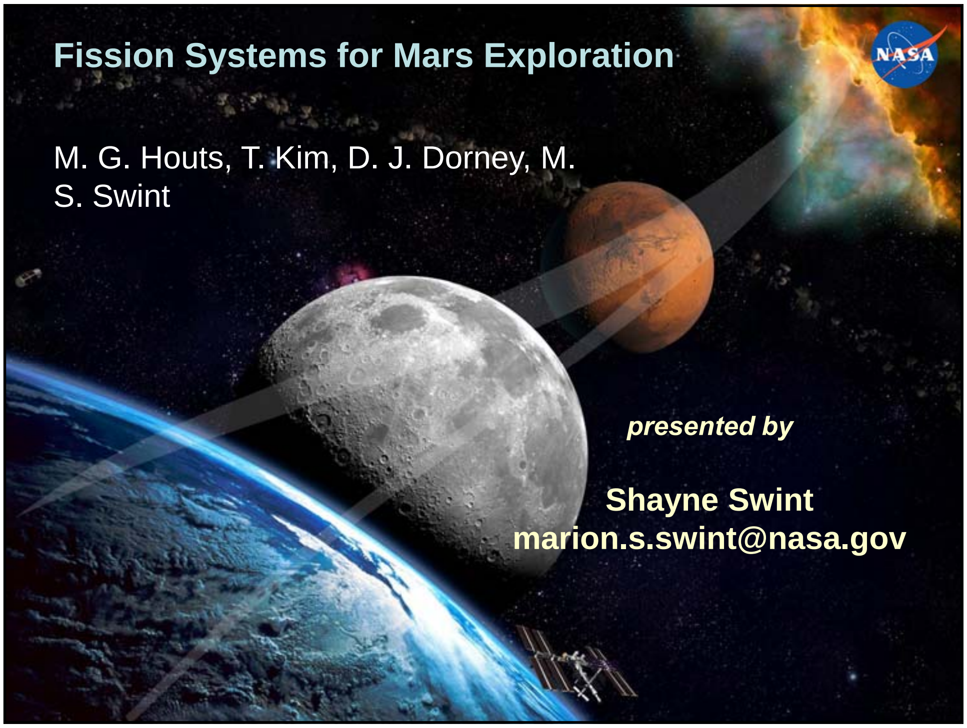
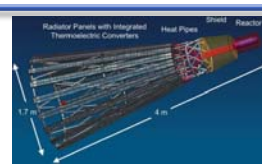


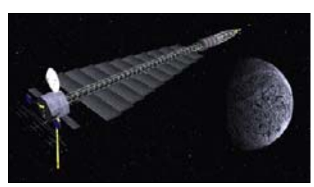
Why Space Fission Power Systems?

- **Extensive experience** (US and international) with a wide variety of fission systems throughout the past seven decades.
- **Abundant power to meet increasing space mission demands**: scalable from kilowatts to megawatts and beyond
- **Potential for very high energy density and long life**: significant performance advantages compared to alternatives
- **Safe during all mission phases**: launched cold, remains subcritical until commanded startup, residual radiation rapidly decreases after shutdown
- **Operationally robust**: high reliability with capacity for contingency operations
- **Environmentally robust**: eliminates dependence on sunlight, resilient under adverse environments (dust storms, high latitudes)
- **Extremely flexible**: can be adapted to a wide range of mission applications
- **Affordable**: detailed studies show development costs are competitive with alternatives
- **Potential Terrestrial Spin-offs:** Low power, compact, autonomous reactors? Basic technologies?
- **Extensible:** Initial, useful fission systems will help enable advanced, extremely high performance fission systems.



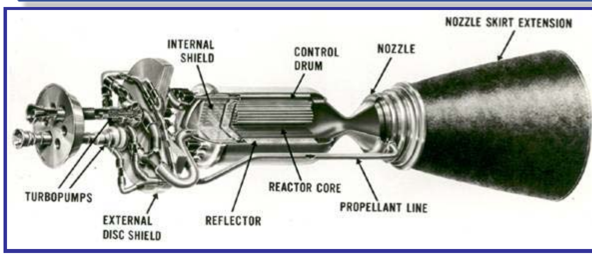
Compact 500 We – 5 kWe Systems

10 kWe – 100 kWe Fission Surface Power



High Performance Nuclear Electric Propulsion

Why a Nuclear Cryogenic Propulsion Stage (NCPS)?



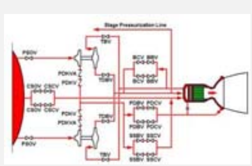
- Nuclear thermal propulsion (NTP) is a fundamentally new capability
  - Energy comes from fission, not chemical reactions
  - Virtually unlimited energy density
  - Promising results from Apollo-era (and other) programs
- Initial systems will have specific impulses roughly twice that of the best chemical systems
  - Reduced propellant (launch) requirements, reduced trip time
  - Beneficial to near-term/far-term missions currently under consideration
- Advanced nuclear propulsion systems could have extremely high performance and unique capabilities
  - Very high T/W, Isp > 1000 s, flexible choice of propellants, etc.
- The NCPS could serve as the “DC-3” of space nuclear propulsion

Ongoing Projects – Nuclear Cryogenic Propulsion Stage

1.0 NCPS Project Management

Project Manager:	Mike Houts (MSFC)	256-544-8136
GRC Lead:	Stan Borowski	216-977-7091
JSC Lead:	Jeff George	281-483-5962

2.0 Pre-conceptual Design of the NCPS & Architecture Integration
Tony Kim, MSFC 256-544-6217

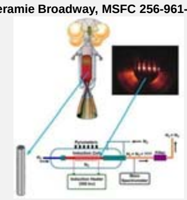


4.0 NCPS Fuel Design / Fabrication
Robert Hickman, MSFC 256-544-8578
Jeramie Broadway, MSFC 256-961-1372

6.0 Affordable NCPS Development and Qualification Strategy
Harold Gerrish, MSFC 256-544-7084

3.0 High Power (≥ 1 MW) Nuclear Thermal Rocket Element Environmental Simulator (NTREES)
Bill Emrich, MSFC 256-544-7504

5.0 NCPS Fuels Testing in NTREES
Bill Emrich, MSFC 256-544-7504
Jeramie Broadway, MSFC 256-961-1372



7.0 Second Generation NCPS Concepts
Rob Adams, MSFC 256-544-3464

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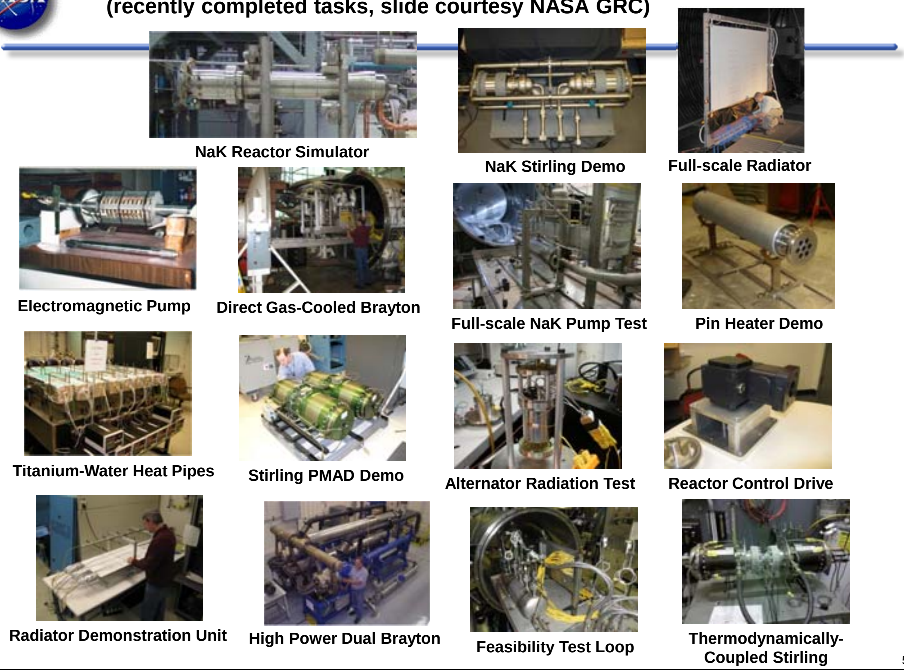
Ongoing Projects: Fission Power Systems
(recently completed tasks, slide courtesy NASA GRC)



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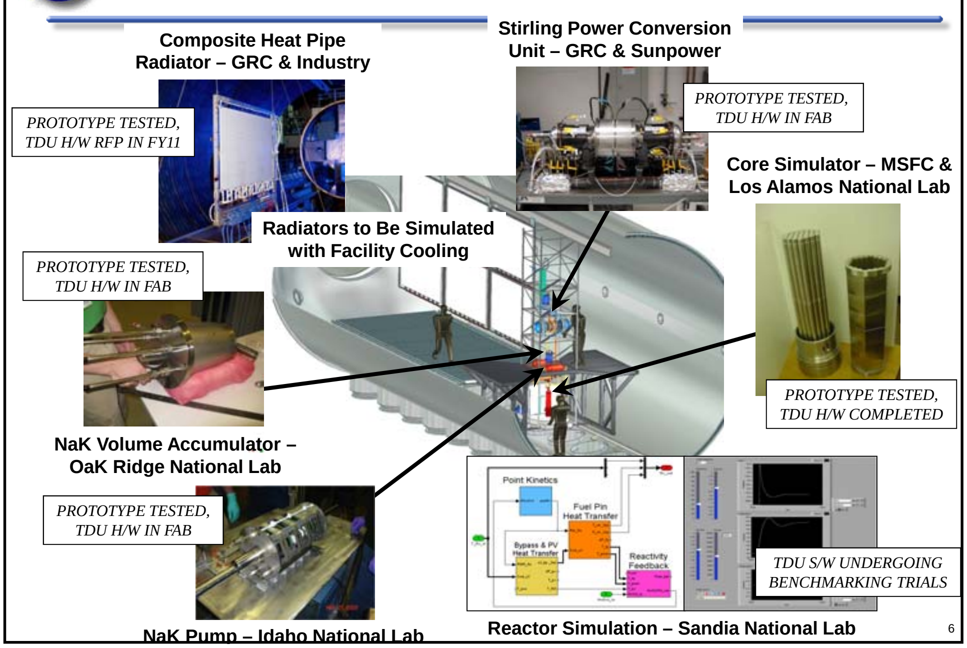
Ongoing Projects: Fission Power Systems
Technology Demonstration Unit (slide courtesy NASA GRC)



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